NOTES ON THE GEOLOGY, PHYSIOGRAPHY AND GLACIOLOGY OF THE KOSCIUSKO AREA AND THE COUNTRY NORTH OF IT.

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(Plates ix–x; Four Text-figures and one Map.)

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Introduction.

The following notes embody the results of observations made by us in the course of a short reconnaissance trip last January, and by one of us during previous short visits, to the Kosciusko area. The principal purpose of the latest trip was to examine the country north of the Snowy (referred to below as the northern area), and in particular, to search for traces of the Pleistocene glaciation in continuation of those already described from the Kosciusko block. For comparative purposes we spent a few days in the latter area examining the glacial evidences, and we were able to note a few features not previously recorded; thereafter we went north, crossed the Eucumbene at Eastbourne and spent a week in the Main Divide country, making our headquarters at the Alpine Hut. The relation of the two areas is shown on the map. Time did not permit us to make an intensive study of any problem, or to link up the physical features of the Kosciusko and northern areas by continuous survey, but we were able to satisfy ourselves that relics of the Pleistocene ice-age are to be found as far as a point on the Main Divide 13 miles north of the latitude of the Kosciusko Hotel, which was the northern limit of our investigations.

The present account can in no way be regarded as final or complete, and many of our interpretations are necessarily tentative and subject to modification; nevertheless we have felt that a useful purpose might be served by placing our notes on record for the benefit of future investigators.

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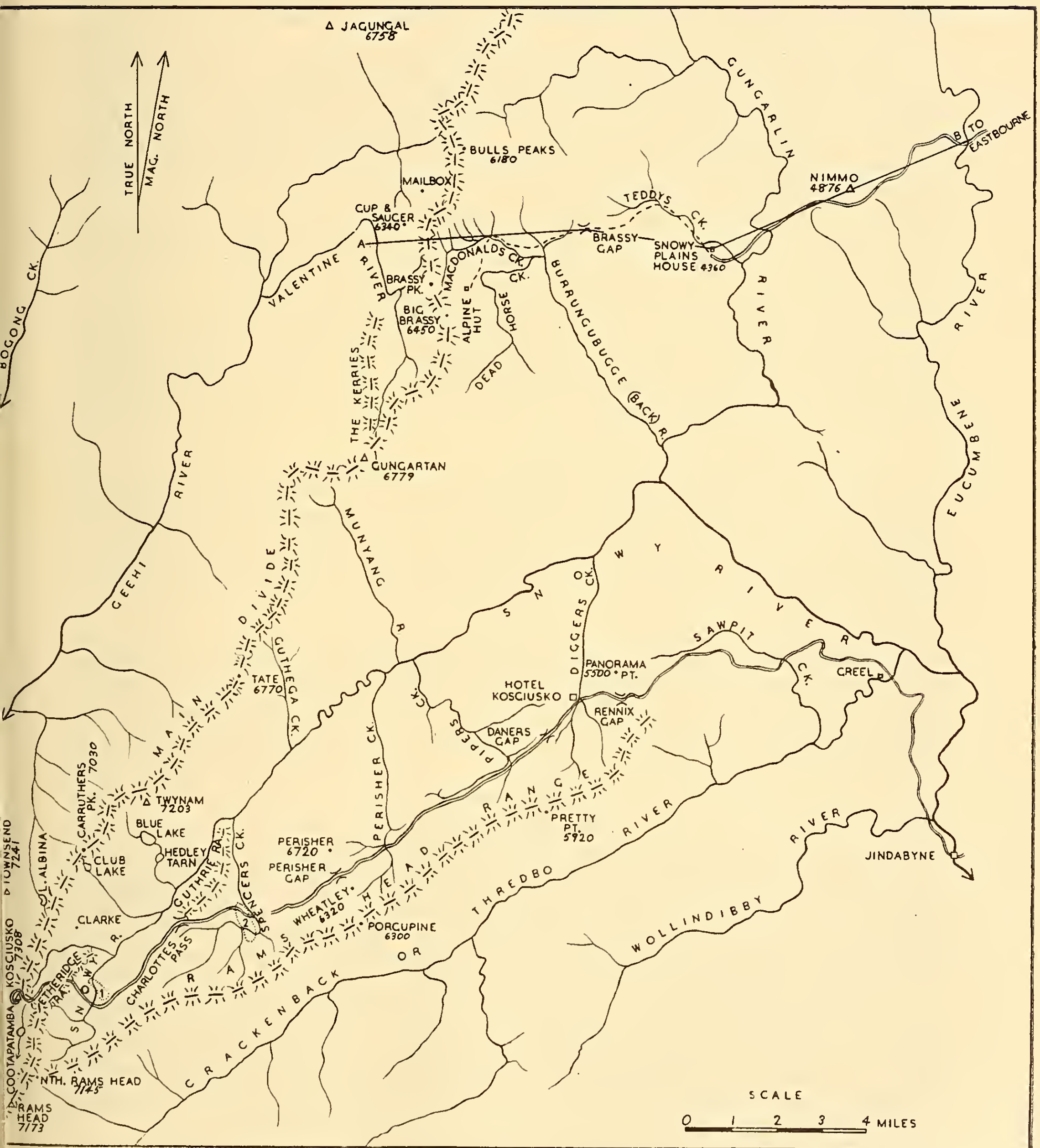
Geology.

Though a specific study of the rocks of the areas visited was not made, it became clear to us that elucidation of the problems of physiography and glaciology will depend in some degree on a knowledge of the geological formations; hence a brief account of our observations will not be out of place.

Nearly all of the country visited is composed of granite, of which two separate intrusions are recognized, apparently of different geological ages. First, and by far the more extensive, is the Berridale bathylith, first encountered along the Berridale road eight miles out of Cooma; with but little interruption it continues west across the Snowy Valley to the Kosciusko block, where it extends to Mt. Twynam, the Blue Lake and the Etheridge Range. From Berridale it passes south well beyond Dalgety and north for many miles towards Adaminaby, and in the northern area it extends west at least as far as the ridge known as the Kerries and north beyond the furthest extremity of the area visited by us. From place to place the granite exhibits variations of structure, texture and composition. For the most part it is massive and fairly coarse-grained, but in the broad valley of the Snowy, near Jindabyne, it is notably finer and less acid, and weathers into smaller joint-blocks. Small outcrops of acid phases—chiefly aplite and alaskite—have been noticed in a few places, and particularly in the northern area. As one ascends the Kosciusko road from the Thredbo River the granite is observed to acquire a rude gneissic structure which becomes very pronounced towards the western margin, where also occasional zones of intense shear may be seen. These features are well shown between the Snowy River and Blue Lake, and they are also very marked in the northern area between Gungartan and Jagungal Peaks. In places the granite contains an abundance of dark xenoliths, which in the gneissic phases become regular *schlieren*. These resist disintegration more strongly than their granite host, and are quite conspicuous among the products of weathering and erosion.



Map 1.—Locality map of the Kosciusko block and the country north of it.
(1 = Masson Moraine; 2 = David Moraine.)

Associated with the granite are co-magmatic minor intrusions of fine-grained diorite, hornblende-lamprophyre and hornblende-porphyrite; these are to be seen both in the Kosciusko block and in the northern area.

The second main intrusion is of well-foliated granite-gneiss, typically developed on Mt. Kosciusko; apart from its appearance between Lake Cootapatamba and Lake Albina, it does not come into the region of the present survey. This gneiss is thought to be of epi-Silurian age, while the Berridale granite may be Devonian or Carboniferous.

Small dykes of basalt are not infrequent in the neighbourhood of Kosciusko, and of particular interest is the dyke of nepheline-tinguaite below the moraine-dam of Hedley Tarn, first noted by David, Helms and Pittman (1901).

The only other rocks of the area are slates, phyllites, quartzites and quartz-schists. Upper Ordovician graptolites have been found in the black slates in various places near Berridale, and it is probable that all the metasediments are Ordovician. They form scattered outcrops of some size, most of which appear to be roof-remnants to the granite intrusions. One large mass, however, is about seven miles wide on the Dalgety-Jindabyne road near Beloka, and extends through a vertical distance of at least 1,200 feet; it continues to the north making a prominent ridge, and is about four miles wide where crossed by the Berridale-Jindabyne road, but tapers out and disappears a few miles farther north. This may be a gigantic inclusion in the Berridale granite or perhaps a kind of screen separating two separate intrusions of magma.

Probably of similar kind is the belt of sediments three or four miles wide traversed by the road from Eastbourne to Snowy Plains House (Naphthali's Hut) on the right bank of the Eucumbene River. Much of this belt is composed of quartzite, which forms the high and rough ground rising on the road to 1,200 feet above the river and is probably responsible for Mt. Nimmo (4,876 ft.*). The meridional extent of this mass is not known.

Near Mt. Kosciusko, at Lake Cootapatamba and Rawson Pass, the older and newer granites are separated by a narrow tongue of phyllite and quartz-schist which widens considerably to the north, where it forms Mt. Clarke, Carruthers Peak and other eminences, as well as some of the lower ground east of the Main Divide. This belt, if it persists, must pass west of the country examined by us in the northern area; the smooth profiles of some of the hills west of Gungartan Peak suggest that they may be phyllitic.

A word should be said about the prevalence of jointing in the granite on the high plateau, which has been brought into much prominence by frost-weathering. Vertical jointing with submeridional and east-west trends is conspicuous, and subhorizontal joint-planes are very common. There is evidence, particularly at Lake Albina and the Blue Lake, that these last influenced to some extent the erosion of rock-material by the Pleistocene glaciers.

Physiography.

Kosciusko Area.

The high plateau trending north and south through Mt. Kosciusko, and containing the Main Divide of eastern Australia which separates the Snowy and Murray River-systems, is part of the early Miocene peneplain which has been raised to its present elevation by a series of movements culminating in the late Pliocene Kosciusko uplift (Andrews, 1910), and from many points of vantage the appearance of the plateau is seen to be that of an uplifted peneplain, albeit much modified by dissection.

The broad, trough-like valley of the Snowy River above Jindabyne, and its continuation to the south as an undulating lowland traversed by the Mowamba and other Snowy tributaries, have been considered to form a fault-trough or sunkland bounded east and west by the horsts of Barney's Ridge and the Kosciusko block respectively (David, 1908; Sussmilch, 1909). The discussion of these matters is beyond the scope of the present

* Heights marked on the map have been taken from the Map of the Snow Leases in the Shires of Snowy River and Tumbarumba, published by the New South Wales Department of Lands in 1943. Other heights given in the text are from our own aneroid readings and are only approximate.

paper, but it may be noted first, that the granite of the broad valley is finer-grained, less acid, more closely jointed and more easily weathered and eroded than that of the higher ground to east and west, and in the second place that the valley walls close in to the north above the confluence of the Thredbo, Snowy and Eucumbene Rivers. There is a suggestion, therefore, that the local widening of the valley is a function of rock-composition and structure and of the increased volume of water available for the work of erosion. But while considerable doubt exists as to the tectonic origin of the Snowy Valley, there are some reasons for believing that the Kosciusko block is bounded on the east by faults. Observations made during the recent trip and on previous occasions suggest most strongly that the plateau descends to the Snowy Valley by a series of giant steps or terraces. From Jindabyne the lower ones are scarcely discernible owing to their dissection by the Thredbo River and Wollondibby Creek which flow obliquely across them. On the ascent by road from the Thredbo River, however, a number of steps is crossed, indicated by relatively level stretches of road and in some instances by the presence of swampy flats (Fig. 1). The first terrace is reached less than a mile past the Thredbo Bridge at a height of about 3,200 feet; this appears to be equivalent to the upper floor

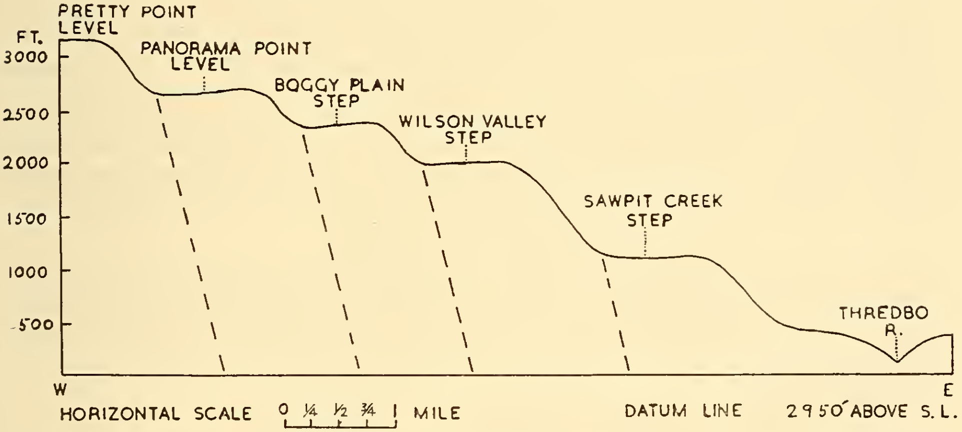


Fig. 1.—Sketch-section across the Kosciusko scarp from the Thredbo River bridge westward. (Broken lines represent hypothetical faults.)

of the broad valley in which the Snowy and Thredbo are incised. A second step, whose existence was recognized by David (1908), is seen near where the road crosses Sawpit Creek at about 4,000 feet; another is at Wilson's Valley (4,850 ft.) and yet another at Boggy Plain (5,200 ft.). This last is particularly well seen on both sides of the road below Rennix's Gap, and the photograph (Plate ix, fig. 1), taken in 1922 from a point some distance south of the road looking north or north-east, gives a clear impression of the step from its western boundary to the edge where it descends to the next step. Like some of the others, this terrace has a slight tilt to the west.

Above Boggy Plain the ground rises to 5,500 feet at Alpine View and Panorama Point, so that from the Thredbo Bridge there is a rise of nearly 2,550 feet in a horizontal distance of six miles. This does not mark the upper limit of terracing (though it is no longer perceptible from the road), for in 1908 David suggested that a fault with a throw to the east of about 200 feet passed just east of Pretty Point in a general northerly direction along Digger's Creek, and from an inspection of the map recently issued by the Department of Lands it would certainly appear that greater elevations are attained on the west than on the east of Digger's Creek, though dissection of the *terrain* prevents the eye from appreciating this fact from most aspects. The Pretty Point terrace, between 5,900 and 6,000 feet high and about five miles wide, probably constitutes the most extensive surface on the Kosciusko block, and it is the level which forms the sky-line of the plateau when viewed from Jindabyne.

A marked increase in the elevation occurs west of the line of Perisher Creek, strikingly brought out in the form-line map in the paper by Taylor, Browne and Jardine (1925). The summit-levels in this much-dissected area are all well above 6,000 feet, and include The Perisher (6,720 ft.) and Paralyzer, Mt. Twynam (7,203 ft.), Carruthers Peak (7,030 ft.), the ridge running north-east from Ram's Head to the Porcupines separating the Snowy and Crackenback (Thredbo) Rivers, and the culminating eminences of Mt. Townsend (7,241 ft.) and Mt. Kosciusko (7,308 ft.). From the neighbourhood of Pretty Point it is possible to look west across the Pretty Point surface and observe in the distance the higher levels rising above it; conversely a view to the north and north-west from some of the higher points in the Perisher group reveals the peneplain surface of the Pretty Point terrace at a lower level, furrowed by the Snowy River and its tributaries. From points of vantage east and south-east of Jindabyne it is possible to trace the terrace far to the south, with the higher points of the Kosciusko-Perisher surface rising in the distance above it.

Detailed work might well reveal the existence of other terraces in addition to those enumerated; in this connection a series of aerial photographs would be of the greatest value.

The first explanation of the terrace-topography that presents itself is, of course, step-faulting to the east. Since the *terrain* is almost exclusively granitic, the influence of differential hardness cannot come into play on the large scale, and neither the gneissic foliation nor the prevalent jointing can account for the major topographic features. Moreover, the Snowy and Thredbo Rivers and their tributaries show marked valley-in-valley structure. It is difficult, therefore, to escape the conclusion that the present topography has resulted primarily from faulting of a peneplain during its elevation into a plateau, though the highest elevations may be residuals from an older erosion surface.

Northern Area (see Fig. 2).

Crossing the bridge (3,540 ft.) over the Eucumbene near Eastbourne, where the river has cut its bed some 500 feet below the general plateau-level, the road to Snowy Plains rises 1,200 feet in three miles to cross the Mt. Nimmo ridge. In another mile it

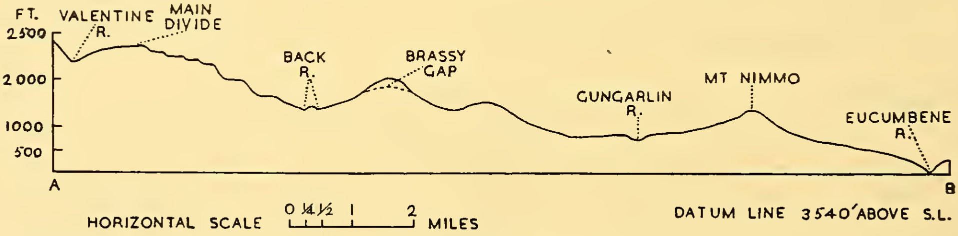


Fig. 2.—Generalized sketch-section across the northern area along the line AB on the map. (Broken lines represent hypothetical faults.)

has reached the edge of the wide, undulating treeless plain forming the valley of Gungarlin River. From Snowy Plains House (4,360 ft.) the track to Alpine Hut rises some 270 feet in two miles along Teddy's Creek, and half a mile farther on, leaves the creek on the right and ascends along the south side of its valley to Brassy Gap (5,375 ft.), a flattish col or saddle some 800 yards wide in a ridge which rises perhaps 200 feet on either side and forms the watershed between the Gungarlin River and its tributary the Burrungubugge or Back River. At the point where the track leaves Teddy's Creek there appears to be a terrace at 4,900 feet, but no other suggestion of terracing has been observed between Gungarlin River and the Brassy Gap ridge, though it should be noted that this is about 400 feet higher than the Mt. Nimmo ridge.

From Brassy Gap a distant view to the west may be obtained of a series of terraces which descends from the Main Divide (6,200 ft.) towards the Back River (4,950 ft.) and is partially dissected by Macdonald's Creek and other creeks. The lowest terrace is at 5,280 feet, and at 5,500 feet is another, on which Alpine Hut is situated. This is backed by a rather steep scarp 400 feet high and is succeeded by a flight of smaller steps extending back to the Main Divide.

The Main Divide in this area runs in a general north-north-east direction and varies in height from 6,000 to nearly 6,800 feet, but it includes by no means all of the highest land. Thus it passes through Gungartan (6,779 ft.), but leaves other high points such as Cup and Saucer Hill (6,340 ft.) and Jagungal (6,758 ft.) on the west. The last of these towers above the general level of the plateau and has all the appearance of a monadnock, but though Gungartan may also be one, it does not stand out so prominently. The dominating land hereabouts is the ridge known as the Kerries, running north from Gungartan for three miles with gradually diminishing elevation. Its eastern side forms the steep western wall of the somewhat asymmetrical valley of Valentine River.

It was not possible in the time available to explore the details of the terracing in the neighbourhood of the Main Divide, but we had the opportunity of making some reconnaissance observations. Viewed from the top of the hill known as the Big Brassy (6,450 ft.), itself possibly a pre-Miocene residual, the terrace-topography stands out with diagrammatic clearness, and one gets the impression that many of the steps have a gentle tilt to the west, which has induced the formation of shallow lakes or swamps or of longitudinal streams and streamlets. To the south and south-west of Big Brassy one observes the tread of a broad step, or perhaps two shallow steps each about half a mile wide, tilted gently to the west and extending from the foot of the Kerries east to the Main Divide, where there is a drop to the east. This step continues for about two miles north of Big Brassy, and though beyond the hill known as the Mailbox it is not so evident, yet the very gentle western slope from the Main Divide is in sharp contrast to the abrupt eastward drop.

Immediately north and north-north-west of Big Brassy, where for a couple of miles the Main Divide is offset to the west, the step-topography is particularly well exhibited. Not all the scarps which bound the terraces are parallel; some of them converge to form wedge-shaped blocks. Big Brassy itself seems to slope directly down to the Alpine Hut step, but the Divide north from Brassy Peak (6,300 feet) is separated from the lower level by another terrace at 5,900 feet which can be followed by the eye for about two and a half miles to the north. The Alpine Hut step (5,500 ft.) is even more prominent, and can be traced clearly from some distance south of Big Brassy for perhaps three miles, to a point north of Macdonald's Creek. Its eastern edge, where it descends to the 5,280-foot terrace, is well defined. Nearer the Divide, to the north of Macdonald's Creek, a flight of smaller terraces can just be discerned; these have been glaciated and are described in some detail below.

To account for the terracing in this northern area as in the Kosciusko block one is tempted to postulate step-faulting, and certainly the major topographic features from the Kerries almost to the Back River are in harmony with such a hypothesis. East of this there are few, if any, indications of terracing, and the profiles suggest rather an upwarping of a maturely dissected surface. It is possible, of course, that original terracing has been obliterated by erosion.

If meridional faulting was really responsible for the terraces, one might expect to find some signs of dislocation on the western margins of the steps. At a few points we did indeed observe in the granite unusually close-spaced vertical jointing with sub-meridional trend, but no definite evidences of faulting were seen. In future field-work the search for such indications should be regarded as a matter of prime importance.

No definite linking up of any of the northern terraces with those of the Kosciusko area has been effected, but it may be significant that the course of Valentine River which bounds the highest land in the area is collinear with that of Perisher Creek, the eastern boundary of the Perisher block.

Rivers and Lakes.

In the region under consideration, two main trends of stream-flow are manifest. First is the north-east direction which is followed by the Upper Snowy, Thredbo, Wollondibby and Mowamba, and which is also seen in those tributaries of the Upper Snowy whose valleys are traversed for many miles by the Kosciusko road from the hotel to the summit. The streams following this direction cut obliquely across the terraces of the plateau. The other trend, which is submeridional, is well seen in the Snowy above Jindabyne, the Eucumbene, the Gungarlin and a multitude of minor tributaries such as Spencer's, Guthega, Munyang, Perisher, Farm and Digger's Creeks in the Kosciusko block and the Valentine River and Dead Horse Creek in the northern area. The conflict of these two trends has resulted in many boat-hook bends or barbed junctions.

We are unable to offer any general explanation for these peculiarities, which appear to be related to some major regional influence, perhaps of a tectonic nature.* Some of the submeridional streams may be connected with faulting or terrace-formation.

The rivers of the Kosciusko block, especially the Snowy and Thredbo, show clear evidences of rejuvenation, and the Snowy exhibits repeated valley-in-valley structure where it emerges from the highlands (Plate ix, fig. 2). Between this point and Jindabyne it flows some 300 feet below the high floor of its broad valley, and 80 or 100 feet below the top of a shingle terrace. That some at least of the entrenchment followed the recession of the Pleistocene glaciers is indicated by valley-in-valley structure on Digger's Creek below the hotel and on the Snowy at Charlotte's Pass, where it is almost at the head of rejuvenation and an old glacial lake has been drained. The evidences of glacial scour of the valleys and of the formation of temporary lakes are considered below.

An interesting example of the relation of erosion to geological structure is to be seen on the highest part of the plateau. Between the older granite-gneiss of the Kosciusko summit and the newer granite lying to the east is a wedge-shaped mass of phyllite which, like the Kosciusko granite-gneiss, has a general easterly dip. Erosion has been to a large extent guided by the phyllite-gneiss junction, and accordingly we find that Lake Cootapatamba and the stream draining it, the col known as Rawson Pass, one of the headwater tributaries of the Snowy, Townsend Pass and the Lake Albina Valley are all aligned on this geological boundary.

In the northern area we note that at Snowy Plains House the Gungarlin is meandering in a wide grassy valley some 30 feet below an alluvial terrace. Here it is flowing roughly south and parallel to the Eucumbene but at 800 feet above it. Lower down its valley becomes deeper and steeper and we understand that at its junction with the Snowy it has cut a precipitous gorge some 1,350 feet deep. From Snowy Plains to its mouth, the river falls some 560 feet in about nine and a quarter miles, and it is flowing against the slope of the plateau-surface. The Back River, where the Alpine Hut track crosses it, is about 550 feet above the Gungarlin and in a much less mature valley; it, too, becomes deeply entrenched before its junction with the Gungarlin. It appeared to us that these rejuvenated streams, as well as the Snowy and Thredbo, must date back to a time anteceding the final uplift of the plateau at the close of Pliocene time.

Some interesting details of drainage are to be seen in the neighbourhood of the Main Divide. The longitudinal course of the Valentine River appears to have been influenced by the tilted terrace lying just east of the Kerries. Macdonald's Creek, a consequent tributary of the Back River, has cut its way through a series of terraces near the Divide, and is joined by a number of tributaries draining them longitudinally. Dead Horse Creek east of Big Brassy is a longitudinal stream, which flows north along the Alpine Hut terrace for some distance and then turns sharply to the east and descends rapidly towards the south-flowing Back River. A col separates it from Macdonald's Creek, and the indications suggest that it formerly joined the latter and was subsequently captured through headward erosion by another tributary of Macdonald's Creek.

It is noteworthy that the valleys on the higher parts of the plateau are mature to old, and that many of the streams meander about, sometimes in rather swampy ground (Plate x, fig. 1), very much as in the Kosciusko area.

Glacial Evidences.

Kosciusko Area.

In his 1908 paper, David pointed out that the Kosciusko area had experienced two phases of Pleistocene glaciation, the first and more extensive an ice-cap glaciation, the

* David (1908) suggested faulting along the valley of the Thredbo River.

second expressed in valley-glaciers. He enumerated and described several of the manifestations of both phases and his observations were added to by the work of Taylor, Browne and Jardine. The following notes may be regarded as supplementing and amplifying the work of previous observers.

According to David, the ice-sheets of the earlier glaciation overrode the existing topographic features, crossing the Snowy River and mounting the ridges to the east. On this and a previous excursion new evidences as to the route taken by the ice were seen. Reference has been made to a dyke of nepheline-tinguaite about half a mile below Hedley Tarn. This rare rock-type, easily recognizable in hand-specimen, has not been discovered elsewhere *in situ* in the area, but erratics of it have been found one mile south-south-east of the dyke on top of the Guthrie Range, as well as in the David moraine in Spencer's Creek. There can be little doubt, therefore, of the direction from which the ice was moving, and significant in regard to the thickness of the ice-sheet is the fact that the blocks picked up from the dyke must have been carried down to about 5,500 feet and then raised through a vertical distance of more than 600 feet to be deposited on the Guthrie Range.

Another piece of evidence suggesting that the ice-sheet crossed the Snowy was provided by the finding of glacially-striated stones of quartzitic phyllite near Charlotte's Pass on the right or eastern bank of the river and at heights of 130 and 140 feet respectively above it. Actually it would appear that much of the slope forming the eastern side of the Snowy Valley from the Masson moraine to Charlotte's Pass is covered with a veneer of ice-borne boulders, mostly of granite but including also quartzite and phyllite, embedded in a somewhat gritty matrix. Where this matrix has been locally washed away by snow-fed streamlets the boulders are thrown together with open spaces between. The above description applies equally to much of the country bordering the road on the east as far down as Rennix's Gap, and the suggestion may be made that the boulders really form a kind of ground-moraine left behind by ice-sheets which came from the high land immediately to the west and north. Many of these eastern (or west-facing) slopes are much more gentle than those on the west, and their profiles are very suggestive of *roches moutonnées*. A good example is afforded by Mt. Wheatley, south of the Perisher Gap, as viewed from the north-east (Plate x, fig. 2). Similar profiles are exhibited at intervals along the Snowy-Thredbo divide between the Porcupines and Pretty Point. No smoothed rock-surfaces have been observed on the gentle slopes, partly because of the covering of ice-borne boulders, partly also, no doubt, on account of post-glacial weathering and erosion.

It would appear that, as suggested by David, the ice-sheets originating in the high country between Mts. Kosciusko and Twynam crossed the Snowy, mounted the slope of the Ramshead Range and spilled over into the Thredbo Valley partly through the boulder-strewn marshy flats or cols which are so characteristic of the Ramshead Range. To do this, part of the ice-sheet had to mount the Guthrie Range and cross the valley of Upper Spencer's Creek. When the ice-sheet dwindled and lost thickness its course was directed by the valleys it had crossed; thus one part passed down the valley of Spencer's Creek wherein it deposited the David moraine, while another branch made its way down the Snowy Valley from its head. This glacier must have been of considerable size and power, to judge from the truncated spurs (Plate x, fig. 3) which are to be seen when one looks downstream from the neighbourhood of Charlotte's Pass. How far it went down the river has not been determined, but it eventually shrank back to a point near the road-crossing, where it deposited the Masson moraine.

From the neighbourhood of the Perisher and other gathering-grounds to the north-east, the ice-sheets moved south or south-east, crossed the valleys in which the road runs, and made their way up the opposite slopes and over into the Thredbo. At a later stage the shrunken glaciers moved down the headwater valleys of Perisher, Piper's and other creeks parallel to the road and then turned north along the main creeks towards the Snowy. The lowest and most northerly of these valleys is that in which is situated the golf-course of the Kosciusko Hotel at a height of 5,000 feet; so far as we know this marks the lower limit reached by the ice in the Kosciusko area, though it may have continued down the valley of Digger's Creek below the hotel.

The passage of glacier-ice down these valleys is indicated by their typical U-shaped cross-sections and flat floors, by the presence of small *roches moutonnées* in Perisher Creek and a small moraine in the golf-course creek, and by the fact that not infrequently the heads of the creeks are found to occupy little hanging valleys. Near the road, at two miles past the hotel, one may see where the Piper's Creek glacier cascaded over a rock-barrier, now breached by post-glacial erosion.

The wide and definite cols—Daner's, Piper's and Perisher Gaps—over which the road runs were in the first instance the result of erosion by collinear creeks, but they were later widened by the passage of ice, and subsequently, on the dwindling of the ice-sheets, functioned as ice-partings.

The relics of the second or minor glaciation are seen chiefly in lakes like Cootapatamba, Albina, Club Lake, Blue Lake and Hedley Tarn, and in cirques and drained lakes with moraine-dams. Most of these have been described already, and we have made only a few supplementary observations.

Descending from Rawson Pass (6,930 ft.) along the valley to the south-south-west, we meet first the moraine-dammed Lake Cootapatamba at about 6,740 feet. Beyond this, and at 90 feet below it, a drained lake is enclosed by another moraine, and further down, the creek flows through what has been a more extensive lake, whose rather coarse and gritty sediments are seen in the creek banks at between 6,340 and 6,315 feet. The lake was evidently very shallow, for the creek is in many places flowing over bedrock. From a distance it seems as if the lake had been bounded by a low rock-barrier, but the creek turns sharply west and flows through a little rocky gorge it has cut for itself, while the broad flat plain continues to the south-south-west and ends rather abruptly on the edge of a youthful post-glacial valley. This shallow rock-basin may mark the farthest limit reached by the Cootapatamba valley-glacier.

North-north-west of the Blue Lake, and perched some 250 feet above it, a well-defined little cirque was noted, with walls extending up perhaps a further 200 or 300 feet (Plate x, fig. 4). The breaching of a low bank of moraine has drained the shallow lake formerly impounded on the granite floor of the cirque. The back or western wall is of phyllite, and some fine examples of large perched blocks of phyllite resting on granite are to be seen (Plate x, fig. 5). The water from the cirque drains down a steep little boulder-strewn valley west of the Blue Lake before entering it. On the northern side of the cirque and some 40 or 50 feet above it, another smaller cirque was seen; this was partially filled with snow, and it would be hard to say how far its excavation was Pleistocene and how far it is the result of present-day nivation.

By far the most impressive cirque in the Kosciusko area is an unnamed one lying close under the Main Divide just north of Mt. Clarke and deeply incised behind it. It is the best part of half a mile in diameter, with walls perhaps 400 feet high. It does not contain a lake, though its exit is partly blocked by moraine. A projecting spur separates it from the cirque—smaller but still impressive—containing the Club Lake.

The lowest cirque we observed is that on the eastern slope of the Perisher near the road. Its floor is about 5,800 feet above sea-level, and it hangs above the valley of Perisher Creek. It possibly belongs to the waning phase of the earlier glaciation.

Northern Area.

This area, too, we consider, exhibits relics of both the earlier and the later Pleistocene glaciation, though these are by no means so striking and convincing as at Kosciusko. For the ice-cap phase the chief gathering-ground appears to have been the Kerries ridge, and since we have not examined its western side we can speak only of the east. Ice-sheets appear to have moved eastward and in a general way downward, passing over the Main Divide. No definite indications of mass-movements of ice have been observed below 5,800 feet, though lobes or tongues descended to lower levels. The ice, of considerable but unknown thickness, cascaded over the scarps of the topographical terraces, by this time somewhat dissected, and modified their profiles.

The chief glacial evidences are *roches moutonnées*, boulder-strewn flats or cols, ground-moraine and terminal moraines.

Among the striking topographic features of the area are the asymmetrical hills and ridges with gentle slope to the west and steep faces to the east, which, like their counterparts in the Kosciusko area, convey more than a suggestion of glacial abrasion, even though their configuration may have been in the first instance imparted by step-faulting. Examples on a large scale are seen south and west of Brassy Peak between Valentine River and the Main Divide (Plate ix, fig. 3); another example is afforded by the ridge culminating in Brassy Peak, with its bare rocky slopes that seem to have been smoothed by ice and modified by exfoliation (Plate ix, fig. 4). Big Brassy itself, towering to 6,450 feet, is the greatest of them all. In addition there are, particularly in the country immediately north of Big Brassy, numbers of low, rounded hillocks of granite which, though less striking, are apparently also *roches moutonneés*. It is true that for the most part the smooth-seeming curved profiles of the ridges are found on close inspection to be roughened and boulder-strewn, but this may well be the result of post-glacial weathering.

Numerous flats or cols, exactly similar to those in the Kosciusko area by which tongues of the ice-sheets made their way into the Thredbo Valley, have been observed down to a level of about 5,450 feet. One of the largest is that on the Main Divide, separating Brassy Peak and Big Brassy at a height of 6,160 feet. Doubtless these depressions were originally water-made and were widened and flattened by the passage of the ice. One col trending east-west on the gentle western slope from the Main Divide, near Bull's Peaks, is cut in phyllite, apparently a great inclusion in the granite, but, contrary to expectation, it contains no granite boulders, and their absence is hard to explain. Evidently there is room for further investigation into the origin of these cols.

The flat valley about a quarter of a mile wide, by which the track ascends from Back River to Brassy Gap, is for the most part treeless and grassy and in places boggy, but along the creek that flows down one side there are in places great masses of granite boulders piled tumultuously with no trace of solid rock to be seen. The arrangement suggests glacial deposition, but further examination is necessary. It appeared to us that Brassy Gap and a similar col in the same ridge might possibly have provided outlets for lobes of an original thick ice-sheet moving eastward from the Kerries to the Main Divide and across the Back River. If this suggestion be correct there should be some traces of morainic material on the eastern fall of Brassy Gap along Teddy's Creek. This is relatively steep and thickly forested and we did not examine it. It is possible that, as at Kosciusko, the ice-sheet in its waning stages broke up into small glaciers which moved along the longitudinal river-valleys. The valley of Valentine River bears some suggestion of glacial erosion, as do the headwater tributaries of Macdonald's Creek, particularly that running north from Big Brassy. The glacier in this valley may have had an outlet to the Alpine Hut terrace immediately north-west of the hut, where there is in the scarp a recess partly filled with moraine.

Another noteworthy feature of this northern area, particularly at the higher levels where vegetation is scanty, is the profusion of granite boulders strewn over the cols, and indeed over the surface generally, though not with the prodigality characteristic of the Kosciusko area. Some of these boulders are manifestly the result of weathering *in situ*, but a large proportion should probably be regarded as ground-moraine. Distinction between joint-blocks and erratics is in general difficult, except where acid phases of the granite exist. On the east and north-east of the Mailbox Hill, for instance, alaskite forms small but conspicuous outcrops, and large boulders of this rock were found half a mile away to the east and uphill from the outcrops, indicating glacial transport. It seems possible that careful mapping of the sparsely-distributed variants of the granite may enable estimates to be made of the extent and direction of ice-movement.

An examination of the country near the Main Divide immediately north of Macdonald's Creek heightens the impression of glacial sculpture by ice moving from the west. The Divide, at an elevation of about 6,200 feet, is a rather insignificant feature, with a gentle westerly slope towards Valentine River along a flat and somewhat marshy tributary valley. The small east-facing scarp of the Divide, 150 feet high, is mainly of solid granite, but partly of moraine-material—tumbled boulders in a matrix of granite-grit and soil. Succeeding this to the east are a series of three or four shallow steps (see Fig. 3) each partly occupied by a swampy flat dotted with granite boulders, and each fronted by a scarp composed partly of masses of smoothed solid granite—evidently *roches moutonnées*—and partly of morainic material (Plate ix, fig. 5). The first two steps are each about one-quarter of a mile broad, and their bounding scarps about 100 or 150 feet high; the third step is much wider and is really double, being crossed about the middle by a small scarp perhaps 50 feet high. On the south, the flat valley of Macdonald's Creek, starting in a col in the Main Divide, collects the drainage from the steps, and on the north, another branch of the same creek flanks the steps, gathering in tributaries from the solid granite country on its left bank. These latter head in cols and are flat and evidently ice-worn; indeed the main creek is barred by two low moraines about 100 or 150 yards across, one at 5,900 and the other at 5,950 feet.

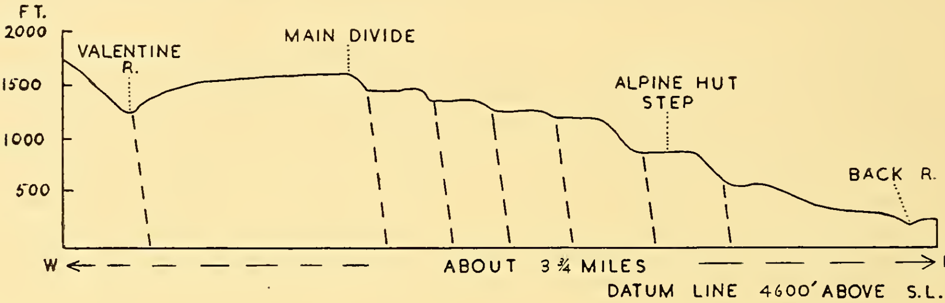


Fig. 3.—Sketch-section across the terraces north of Macdonald's Creek.
(Broken lines represent hypothetical faults.)

The third step, with its lowest edge at about 5,800 feet, has a number of flat outlets to the east partly filled with moraine, and it would seem that the ice-sheet gouged these out in its passage over the scarp. There is a steep drop of about 400 feet on to the next level, which is really an eroded northern continuation of the Alpine Hut step. The scarp has suffered a good deal of dissection, and in particular the northern branch of Macdonald's Creek has cut a deep cirque-like recess into it (Plate ix, fig. 6). The course of Macdonald's Creek across the Alpine Hut terrace is marked by a profusion of tumbled boulders, and these become more abundant and conspicuous where the creek flows from the terrace down one side of a flat-floored valley to Back River. The tumbled material, which includes some quartzite as well as granite, and whose boulders may be up to 12 feet in length, extends through a vertical interval of 200 feet to a level of 5,180 feet, which marks the lowest elevation at which we have seen what we consider to be morainic material. From the Main Divide to this point there is a total drop of 1,000 feet in a horizontal distance of two miles.

Though no ice-scratched stones and no striated pavements were found, we feel reasonably sure that the present topography has resulted from the passage of ice over a flight of terraces—perhaps due to step-faulting—that had been modified by river-erosion. We are unable to say whether the ice-sheet in its prime crossed Back River and reached the ridge containing Brassy Gap, but certainly lobes or tongues of ice, perhaps during the waning phase, made their way over the scarp on to Alpine Hut terrace, and one of them followed the valley of Macdonald's Creek down for some distance towards Back River, the valley being choked by moraine on the retreat of the glacier.

It was somewhat surprising to find that moraine-material had survived as scarps to the steps, but doubtless it is preserved from erosion by the adjacent outcrops of solid granite as well as by the covering of snow which lasts for several months of each year.

Gungartan Peak is composed of large joint-blocks of granite, very evidently *in situ*, and we could find no signs of glaciation in its immediate vicinity; possibly it projected as a *nunatak* during the maximum glaciation. The country to the west of it is smoothed as if by glaciers and contains what appear to be small *roches moutonnées*, but we had not time to examine the area east, west or south of the peak.

The features tentatively attributed to the later glaciation consist entirely of cirques. Five of these were observed:

(1). At the head of Valentine River three-quarters of a mile north-north-east of Gungartan Trig. Station at 6,550 feet. A little hanging valley 50 or 60 feet above the main valley-floor, with a wall not more than 50 feet high. A small moraine formerly dammed a lake now drained.

(2). High up on the left bank of Valentine River three-quarters of a mile above Mawson's Hut, at about 6,130 feet. Observed from the right bank.

(3). On the eastern slope of the Kerries at about 6,270 feet and at a point whence Big Brassy bears 51°. The walls are not more than 100 feet high and no definite moraine is visible, but the floor may have contained a shallow lake.

(4). About one and a half miles north-east of Gungartan Peak. A little cirque at 6,300 feet with a wall about 50 feet high in a creek draining to the north-east.

(5). A little to the south-west of Big Brassy. A drained lake occupies a hollow, really a small cirque, at 6,125 feet.

Our observations on glaciation extended only for a mile north of Bull's Peaks. Quite probably Jagungal (6,758 ft.) or its immediate environs will yield some glacial evidences, but this should mark their northern limit, for the plateau beyond this point seems to be too low to have been under Pleistocene ice.

SNOW-PATCH EROSION AND NIVATION.

The time of our trip was particularly favourable for observing snow-patch erosion because there had been heavy snow falls during the previous winter, and, the early summer being cool, snow was preserved to a greater extent than usual. Countless snow-patches lay all along the eastern side of the main ranges from Kosciusko to Jagungal. The patches generally decreased in size and in number in the lower elevations to the north.

Most of the snow-patches in the Kosciusko region were of what may be called the 'transverse' type, the major axis lying transverse to the line of drainage. As the summer progressed the transverse had subdivided to form longitudinal snow-patches, elongated downhill, in those hollows where the snow was thickest.

The primary reason for the formation of transverse snow-patches, which all occur below the crest of east-facing slopes, seems to be that the snow falling on the crest of a ridge is blown clear of the summit by the prevailing westerly and south-westerly winds; it thus comes to rest and accumulates to greatest depth on the sheltered slopes some 50 to 100 feet below. The chief factor in its preservation would appear to be the greater bulk accumulated in such situations compared with surrounding slopes. Thus the slopes can be differentiated on their capacity to collect and retain drifting snow. Those with the greater capacity are subject to different denudational processes from those which lose their snow early. When the snow thaws early in the season, the vegetation grows quickly and forms a protective cover, but when the snow-patch lasts far into the summer the vegetation is killed and the surface is bared. This results in (*a*) acceleration of the processes of nivation on the slope while snow is present, and (*b*) acceleration of erosion by rain run-off when the snow disappears.

At the altitudes at which the snow-patches occur, severe frosts occur at night during all times of the year except mid-summer. In addition during the bright winter days a thaw occurs, as is indicated by the waning of the snow-covered areas between each fall of snow.

Undoubtedly, therefore, the process of nivation is active at all times of the year as long as the supply of moisture remains adequate, that is, in those areas where a large volume of snow has accumulated. Alternate melting and freezing shatters the bedrock below the melting snow-patch, and the loosened fragments themselves are broken up, yielding supplies of fine material.

The snow-patches in the whole of the region showed little or no sign of downhill movement, so that apart from gravity all the transport is done by thaw-water. Only one snow-patch, south of Club Lake on a slope of some 30°, was found to have developed a crevasse. Whether this was due to the movement of the mass over the surface of the ground, or to differential movement or slumping within the mass, could not be determined.

The most extensive transverse snow-patch or drift observed extended in a serpentine form below the crest-line from the summit of Kosciusko almost to Northcote Pass, a distance of one and a half miles. It varied in width from a few yards to about 30 yards. Some of the patches farther north in the vicinity of Blue Lake and Mt. Twynam averaged about 50 yards in width.

The effects of snow-patch erosion were best exemplified in the steep slopes forming the cirque wall of Club Lake. Plate x, fig. 6, shows the conditions existing during late January, 1944. The longitudinal snow-patches are obviously the remains of a continuous transverse snow-patch. The bare slope was being actively eroded by nivation and thaw-water, which, below the snow-patch, issued in well-defined runnels and carried débris forward to build a delta out into Club Lake.

In the northern area, the snow-patches were very much smaller in extent and had obviously been more extensive during the early summer. All that remained in most cases was a patch some 50 yards long and 5 to 10 yards wide. Observations on the slopes on which these occurred are generalized in Fig. 4.

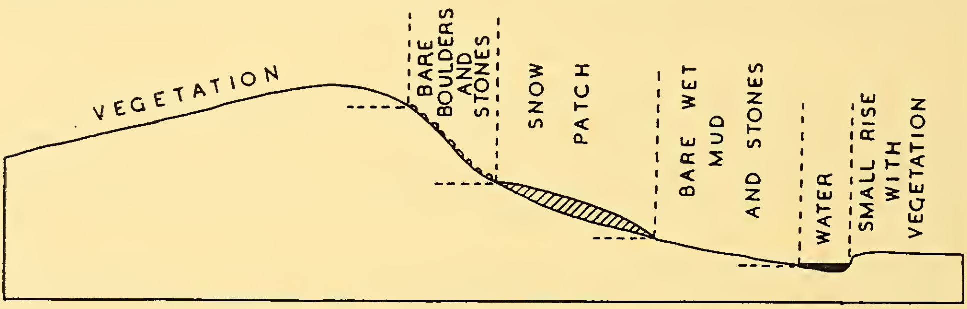


Fig. 4.—Diagrammatic section of a snow-patch and its environment.

The west-facing slope is gentle and at altitudes below 6,000 feet is well covered with vegetation. Below the crest on the east-facing slope, the ground is bare of vegetation and rock-outcrops, boulders, stones and soil are exposed. At the time of our visit, the snow obviously had only recently vacated this area, and the snow-patch, occurring in the lower middle slope, was small in extent. Below it the slope was bare of vegetation, the surface was wet, and over the mud and stones ran streams of thaw-water from the snow-patch. Skirting the foot of the slope is a long shallow hollow in which the thaw-water was dammed. Below it the ground rises six inches to one foot to the level of the gentle slope or flat beyond. This was boggy and covered with coarse grass, low shrubs and some peat.

The whole of the unvegetated zone from the flat to below the crest was probably caused by a snow-patch in the spring and early summer. During the bright summer days, melting proceeded rapidly, runnels flowing from beneath the snow-patch. The flowing water carried with it, from beneath the snow, fine sand and clay particles. Where it flowed over the sodden surface on the slope below the snow-patch, it moved other particles and built up minute cones and deltas in the shallow hollow skirting the foot of the slope. Where clumps of vegetation barred the course of the runnels, small perched vegetation-dams were built up. On those slopes where the snow-patch had just disappeared the bare slope was scoured by small rills showing active denudation, while the foot of the slope was skirted by an apron of fine deposited material.

Evidence would therefore indicate that snow-patch erosion and nivation are playing an active part at the present day in the denudational processes of the plateau. Snow-patches or nivation-hollows recede a little farther into the slopes during those years when abundant supplies of snow are available.

Since the main cirque-glaciers melted at the close of Pleistocene time, these processes must have been active in moulding the landforms and maintaining the steepness of the slopes. Further work and systematic observation over a period of yêars are necessary to assess the part played by snow-patch erosion and nivation in the sculpturing of the post-glacial landforms.

Upland Swamps.

The high portions of the Kosciusko plateau are characterized by small areas of upland swamp occurring in country, mainly above 5,000 feet, which is covered with snow from seven to nine months of the year. The swamps tend to develop in places where the drainage is somewhat obstructed by dumps of morainic material, topographic features resulting from glaciation, or hard zones in the granite. They are particularly common in cirques and drained lakes, around moraine dammed and over-deepened lakes, and along the mature floors of the U-shaped valleys above the limits of rejuvenation in the streams draining the plateau (Plate x, fig. 1). The accumulation of organic dêbris, derived from the vigorous growth of the swamp-plants, also tends to hold up the drainage, producing vegetation-dams and promoting swampy conditions. This factor is so pronounced, in some places, that swamps have developed on gently sloping surfaces which, under normal climatic conditions at lower altitudes, would have been drained by their gradient.

Upland swamps were seen round the shores of Lake Cootapatamba and the Blue Lake, in drained-lake areas below Lake Cootapatamba and in Hedley Tarn, in cirques along the eastern side of the Main Range between Kosciusko and Mt. Twynam, along the mature floors of the valleys of the Snowy and its tributaries between Kosciusko and Charlotte's Pass and in Upper Spencer's Creek. They also occur in the northern area, where they were observed in small cirques along the eastern side of the Kerries, on the broad valley-floor at the head of the Valentine River, and on the glaciated steps situated on the eastern side of the Main Divide between Brassy Peak and Bull's Peaks.

The vegetation of the swamps consists of plants resembling peat-mosses, small soft herbage and algal material. These plants grow vigorously during the three or four summer months when the ground is free from snow. Observations suggest that the abundant growth each summer is due to the plants having but three or four months to reach maturity and come to seed, as well as to the fact that the ground is completely saturated with water from melting snow in spring, and remains saturated throughout the summer owing to low rates of evaporation at the high altitudes.

At the end of summer, late in March or in April, snow begins to lie on the ground and covers the summer growth of swamp-vegetation almost before it is completely dead. The low soil-temperatures prevailing in winter and the weight of snow tend to preserve and compress the plant-material into firm but spongy, fibrous beds, which, after burial under additional plant-dêbris during successive summers, become immature peat. The beds are able to withstand to a large extent the flowing water which accompanies the spring thaw, and form a strong foundation for the roots of each summer's growth.

The annual development of swamp-vegetation, under the foregoing conditions, has a profound influence on the drainage and soil-formation along valley-floors and on surfaces of little slope, giving rise to tussocky country and to swampy soils which are remarkably springy underfoot.

The vigorous growth and persistent accumulation of organic material frequently cause the vertical peat-like banks of small streams to unite above the flowing water and form a continuous bed of turf beneath which the streams may flow for considerable distances. Such cases appear to be the reverse of soil erosion, the tendency to accumulation of plant-material overcoming the erosive power of the streams. This results in the building up of peaty beds, but they are only temporary, as the breaching of moraines, the deepening of channels draining lakes and the entrenchment of streams due to rejuvenation, eventually lower the water-table, and the peat is removed during the normal processes of valley development.

Summary.

An account is given of observations made on the geology, physiography and glaciology of the Kosciusko plateau and its continuation for some miles to the north.

Step-topography is characteristic, tentatively ascribed to faulting, and traces of the Pleistocene glaciation known to have affected the country around Mt. Kosciusko have been found to extend for several miles to the north.

Observations are recorded on snow-patch erosion and nivation and on the upland swamps so characteristic of the higher parts of the plateau.

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EXPLANATION OF PLATES IX-X.

Plate ix.

Fig. 1.—Boggy Plain step, looking about N.N.E. from a point south of the road.

Fig. 2.—Snowy River gorge at its exit from the Kosciusko block. Note repeated valley-in-valley structure.

Fig. 3.—View south from Brassy Peak showing the Kerries in the background and probable *roches moutonnées* on the step between Valentine River (right) and the Main Divide.

Fig. 4.—View looking from Big Brassy to the N. and N.W. The bare granite ridge running N. from Brassy Peak (on left) is a probable *roche moutonnée*. In the foreground is a step at about 5,900 feet with other smaller *roches moutonnées* on it. On the horizon is the monadnock of Jagungal.

Fig. 5.—Boulder-strewn swampy flat forming second step in the Macdonald's Creek flight. The scarp in the foreground is partly of moraine. Big Brassy (left) and Brassy Peak in background.

Fig. 6.—Looking up Macdonald's Creek towards the 400-foot scarp at the back of Alpine Hut step. Moraine in left foreground.

Plate x.

Fig. 1.—Looking up the valley of Valentine River, which in the foreground is meandering in a swampy flood-plain.

Fig. 2.—Profile of Mt. Wheatley, a probable *roche moutonnée*, as viewed from the north-east.

Fig. 3.—Looking down the Snowy River valley from the vicinity of Charlotte's Pass, showing truncated spur.

Fig. 4.—Flat-floored cirque above and N.W. of Blue Lake, with smaller cirque above it in right background.

Fig. 5.—Phyllite erratic on granite on cirque floor above Blue Lake (in middle distance). Guthrie Range on the horizon.

Fig. 6.—Snow-patches on steep wall of Club Lake cirque.